STRESS DISTRIBUTION IN ORGANIC SOILS UNDER TRAFFIC LOADING

by

NYAL E. WILSON

Associate Professor of Civil Engineering
McMaster University
Hamilton, Ontario

Reprinted from Canadian Peat Symposium
University of Sherbrooke
CANADA

April 1972

PROCEEDINGS OF CANADIAN PEAT SYMPOSIUM, 1972

"STRESS DISTRIBUTION IN ORGANIC SOILS UNDER TRAFFIC LOADINGS"

NYAL E. WILSON
ASSOCIATE PROFESSOR OF CIVIL ENGINEERING
McMaster University, Hamilton
Canada

ABSTRACT:

The breakdown of peat due to the passage of vehicles is an important consideration for transportation across Northern Canada. It is shown that peat has a structure which can sustain loading, but once the threshold load is reached, rapid deterioration occurs.

The stress-deformation patterns produced in the peat by vehicle loading, both by tracked and wheeled vehicles, are discussed so that the mechanism which causes deterioration of the peat can be explained. Suggestions are made for modifications to vehicle design and operating conditions.

Stress Distributions in Organic Soils Under Traffic Loadings

- Nyal E. Wilson

INTRODUCTION

The passage of a single vehicle, either a tracked or wheeled vehicle, produces a complicated stress-deformation pattern in soft ground. If the stresses and deformations exceed the shear strength of the soil, failure of the soil occurs and the vehicle may become immobilized. However, even if the stresses and deformations do not exceed the shear strength of the soil, the soil may experience progressive failure or "fatigue".

The stress-distribution pattern imposed by the track or wheel loading is determined by the design of the track or the shape of the tyre. One passage of a tracked vehicle over organic soils produces a series of repeated loads depending on the dimensions of the track, the number of idler wheels, the position of the centre-of-gravity for the vehicle, the location of the driving sprocket and the flexibility of the track.

STRUCTURE OF PEAT

Peat, generally speaking, is composed of a loose matrix of partially-decomposed plant elements - these plant elements having a cellular structure, usually filled with

water. This cellular structure is shown in Figure 1, which is a photo-micrograph through a sample of fine-fibrous peat. Photomicrographs have shown that the peat contains many different types of water - the free or void space water, the water held within the plant cells and the adsorbed water (Wilson, Radforth, MacFarlane and Lo, 1965).

When the peat is loaded and stress deformations occur, the particles are forced into contact as the free water is expelled from between the particles. The consequence is that the water within the cells is put under pressure; should this pressure exceed the strength of the cell walls, the cells break allowing a release of water to further "lubricate" the peat. The breakdown of the cell structure is shown diagrammatically in Figure 2.

SHEAR STRENGTH OF PEAT

The strength characteristics of peat are relevant to track design. These characteristics can be obtained from a series of repeated loading tests where it is possible to measure the resilient (elastic) and permanent (inelastic) displacements individually. (Glynn, Kirwan, & Wilson, 1968)

A peat sample at a shallow depth below a tracked vehicle experiences a vertical stress (major principal stress) due to the superimposed load, and a horizontal stress (minor principal stress) due to the stress exerted by the adjacent soil; there is also a shear component from the torque of the

vehicle, but this has been ignored.

Samples of fine-fibrous peat (water content 450%) were tested under tri-axial (three dimensional) stress conditions to duplicate field conditions. Repeated loads were used as it is analogous to the conditions associated with tracked vehicles, where it was found that the supporting peat could withstand a limited number of vehicle passes before immobilization occurred with the breakdown of the structure of the peat. Repeated loading under a vehicle has a "piston effect" as the loads are applied and removed by the closely spaced idlers running on the track. The measured stress changes are progressively more abrupt as the number of load repetitions increases; the strength of the peat deteriorates and its ability to spread the load diminishes (Wilson 1968). Figure #3 shows a Nodwell vehicle which has become immobilized after making many satisfactory passes over the peat.

The results of the repeated loading tests are shown on Figure #4, with the permanent axial deformations and pore-water pressures plotted versus number of stress applications. It is shown that, for a vertical stress application of 5 lb./sq. in. the sample withstood 1,000 loadings with minor increases in axial deformation and pore-water pressure. However, when the vertical stress was increased to 6 lb./sq.in., the sample rapidly failed after fifty loadings with major axial deformations associated with a dramatic increase in

pore-water pressures.

The significant increase in pore-water pressures is associated with the breakdown of the fibrous peat and the release of water held within the cells of the peat. The structural breakdown of the fibres of the peat occurs rapidly after the threshold stress has been exceeded. The behaviour has been noted in the field (Hanrahan, 1964) where it was reported that a highway embankment had been satisfactory under normal use, but failed when used by heavy traffic.

Field Stress Measurements

A series of field tests were run on one of the most common and successful vehicles - the Nodwell RN25. Pressure measuring transducers (Fig. #5) were inserted into the peat and the vehicle driven over the instrumented area; Statham pressure transducers, with waterproof housings, were used for extreme accuracy.

The outline of the Nodwell is shown Figure 6 and it is noted that the vehicle is supported by four axles running in a flexible rubber track; the torque sprocket is located at the rear of the vehicle. The average ground pressure was obtained for the vehicle by dividing the weight by the ground contact area. The vehicle was tested unloaded.

The increase in vertical stress experienced by the peat is shown in Figure 7, for the transducer reading under a grouser bar along the centre-line of one track. It can be

seen that the pressure is not uniform and is concentrated near the rear of the vehicle which assumed a "bow-up" attitude to the ground. This attitude may be attributed to the flattening of the muskeg cover as the vehicle proceeds and, to some extent, the sinkage at the rear due to the deterioration of the peat.

The front approach angle for the track is shown as the track is held by the tensioning idler (Figure 8). The flexibility of the track is shown when the vehicle is parked on an uneven road surface. (Figure 9).

It has been found that this type of tracked vehicle can transverse soft and difficult organic soils if driven under full torque; it appeared contradictory, as it was assumed that we should approach soft soils as gently as possible. Transducer readings indicate that the pressures in the peat are not as extreme under high torque as the track is pulled tight by the rear sprocket and the flexibility is reduced. While the tensioning idler at the front maintains the track in correct alignment, it cannot provide sufficient tension to enable the track to spread the load longitudinally. The motor torque reduces the flexibility by pulling the track tight under the axles which improves the stress distribution and reduces the remoulding effect on the peat; it can be shown that a front-drive sprocket could not accomplish the tensioning effect to the same extent. The vehicle is more than a track-laying device and requires that

the track be tensioned to distribute the load.

STRESS VARIATIONS

The readings for four transducers placed at different locations in the peat enabled a stress distribution model to be made; the readings are shown in Figure 10. A model of the readings (Fig. #11) was made to show the variations along and across the track. It is these variations, causing shear stresses and distortions in the peat, which cause the peat to break down after a number of passes.

The ideal stress distribution would be an elongated dome which would impose only one load per vehicle pass - the load being applied and diminished smoothly. The stress distribution pattern can be improved by reducing the longitudinal flexibility of the track; this has been done on some cross-country vehicles where the track linkage has a "knee-action" - it can be bent in only one direction and is not forced upward between the axles. A reduction in flexibility also produces an increase in operating efficiency as the wheels are not forced to climb a gradient continually being formed in front of them. Increasing the number of idler wheels has the same effect as reducing the flexibility and that is the reason why the "Weasel" (Figure 12) was so successful.

The pressure experienced by the peat at the location between grouser bars along the centre-line of the track shows that a plateau is reached at approximately 3 lb./sq.in. for

this peat. This indicates that the shear strength of the peat has been reached and that the soil is being sheared by the grouser-bar and being squeezed up between the bars (Figure #13). This does not happen under the centre-line of the rubber belt because the peat is held down by the belt.

WHEEL LOADING

Field and laboratory research has shown that the passage of a wheel produces a complicated stress-deformation pattern in the soil and cannot be considered as a single load application. Figure 14 shows the behaviour of a driven wheel in soft soil; a mud wave is formed ahead of the wheel, the torque produces shear stresses and movements within the soil and, finally, a wheel rut remains in the soil after the wheel has passed.

In the laboratory research, a series of lead markers were buried in the peat and the movements of these markers were recorded by X-ray photographs during the passage of the wheel (Wilson and Krzywicki, 1966). The movements were consistently "heart-shaped" (Figure 15) as the soil particles were (i) pushed forward, (ii) forced downward by the weight of the wheel, (iii) pushed backward by the torque from the wheel, (iv) moved upwards by elastic rebound, and (v) pulled forward into the rut behind the wheel.

The shape, size and stiffness of the tyre affects the stress distribution. Large diameter tyres, with wide treads,

are preferred for spreading the load. The stresses experienced by the peat are usually greater than the inflated pressure due to the stiffness of the tyre casing. Unfortunately, the tyre casing causes a stress increase at the edge of the loaded area which produces stress concentrations at the most undesireable locations. The shapes and positions of tyre lugs can be designed to minimize these effects.

In the field, the magnitude of these movements can be envisaged by observing the surface distortion during the passage of a wheeled vehicle. Stress deformations are produced within the peat which cause the peat structure to rapidly deteriorate and vehicle operators instinctively avoid previous wheel tracks so that the deterioration is reduced and the virgin vegetation cover assists in spreading the load.

CONCLUSIONS

It has been shown that peat is a material which is very sensitive to structural breakdown, with the consequent release of water from the cells within the plant elements. Vehicle design and operation can take this fact into consideration by reducing the stress deformations imposed on the peat and conserving the vegetation cover to assist the load distribution.

REFERENCES

[1] Glynn T.E., R.W. Kirwan and N.E. Wilson, (1968). "Measurements of the Dynamic Response of Peat Subjected to Repeated Loading". Proceedings of Third International Peat Congress, pp. 128-131.

[2] Hanrahan, E.T. (1964). "A Road Failure on Peat". Geotechnique, 14:3: pp. 185-202.

[3] Wilson, N.E., N.W. Radforth, I.C. MacFarlane and M.B. Lo, (1965). "The Rates of Consolidation for Peat". Proceedings of Sixth International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, pp. 407-411.

[4] Wilson, N.E. and H.R. Krzywicki, (1966). "Soil Mechanics as it affects Vehicle Performance". Canadian Geotechnical Journal, Vol. 3, No. 4, pp. 204-216.

[5] Wilson, N.E., (1968). "Influence of Track Design on Soil Pressures and Deformations". Proceedings of Third International Peat Congress, pp. 60-64.

ACKNOWLEDGEMENTS

This research was conducted with the assistance of the vehicle manufacturer, Robin-Nodwell, under the guidance of Dr. N.W. Radforth. The field work was conducted in conjunction with the Defence Research Board of Canada and the United States Army.

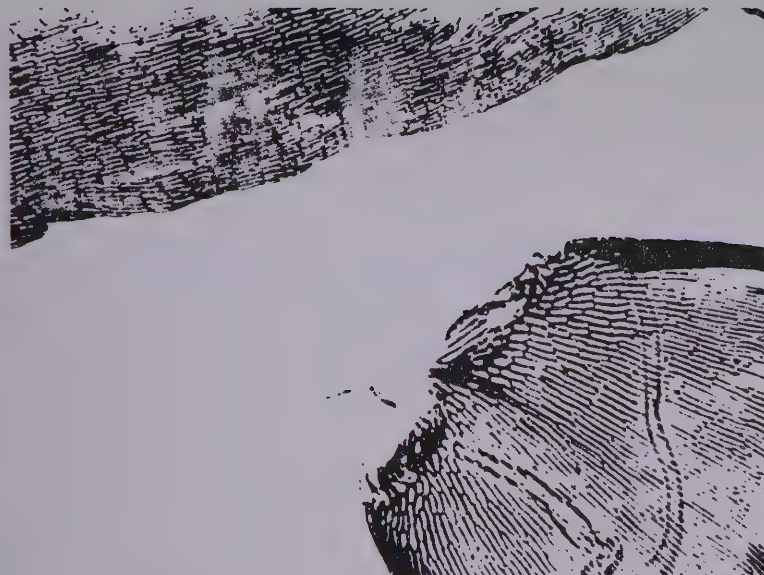


Fig. # 1 - Cell Structure of Fibrous Peat

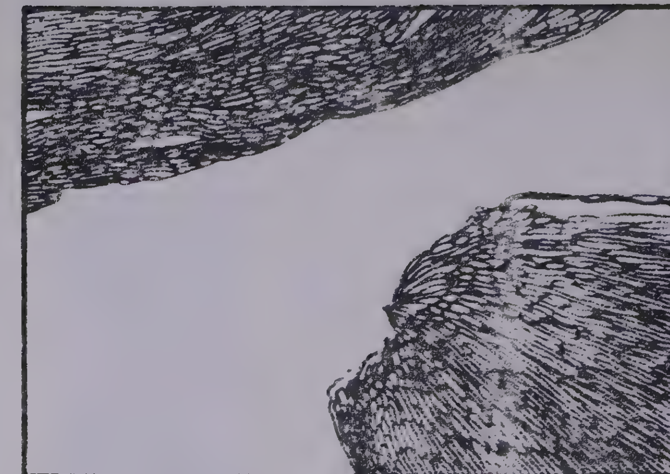


Fig. # 2 - Breakdown of Cell Structure

Fig. # 3 - Nodwell Immobilized

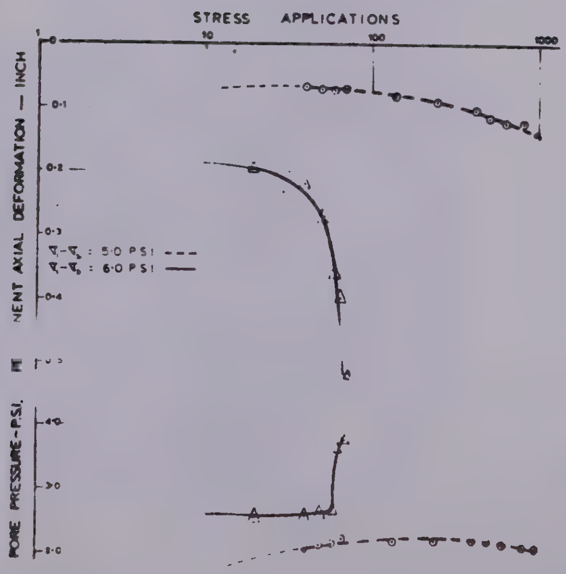


Fig. # 4 - Repeated Loading Test

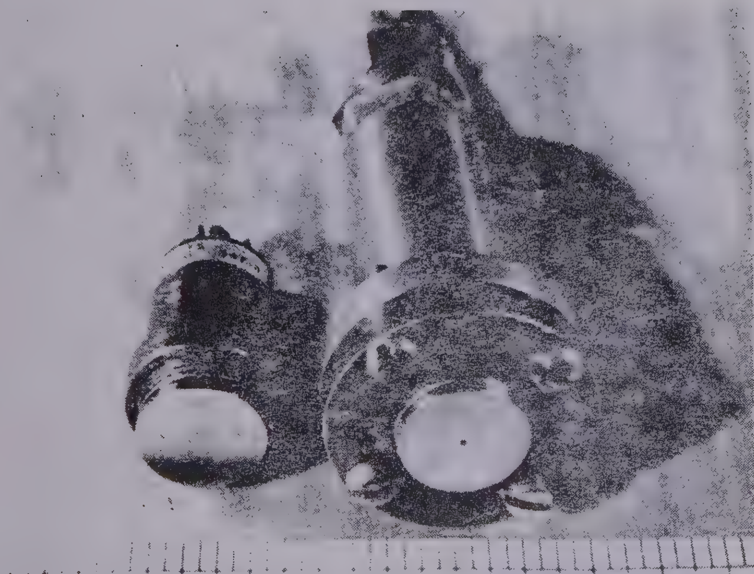


Fig. # 5 - Measuring Transducers

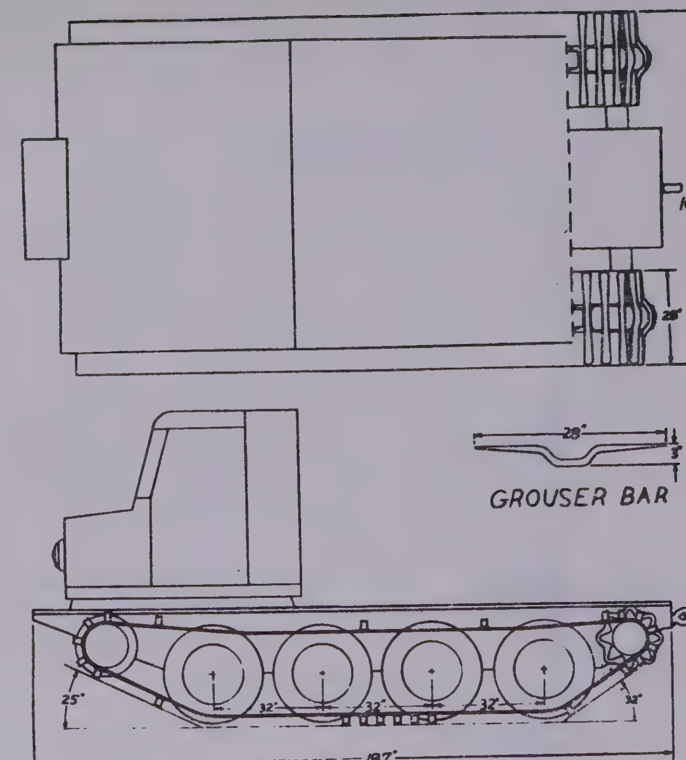


Fig. # 6 - Nodwell RN25

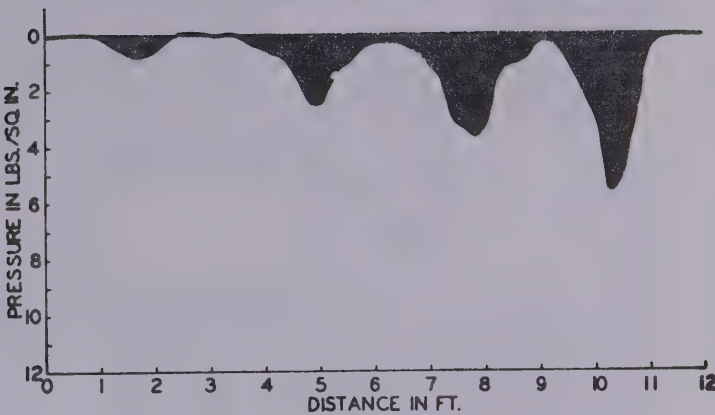


Fig. # 7 - Stress under Grouser Bar

Fig. # 8 - Track Idler

Fig. # 9 - Nodwell Parked

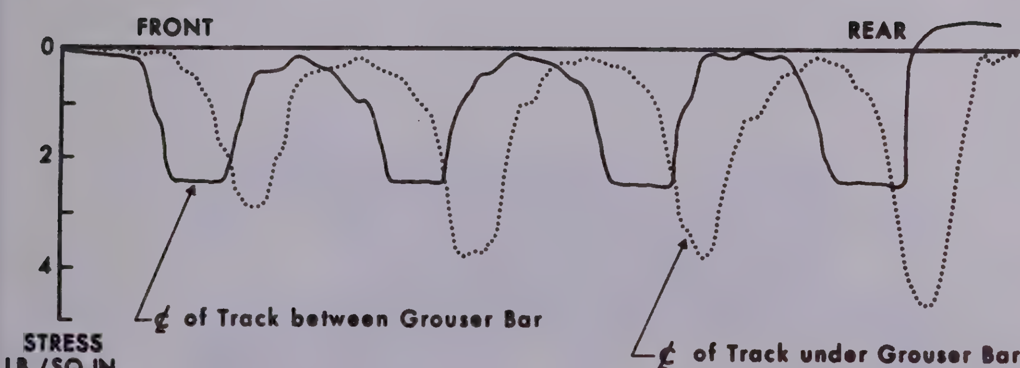


Fig. #10 - Stress Readings

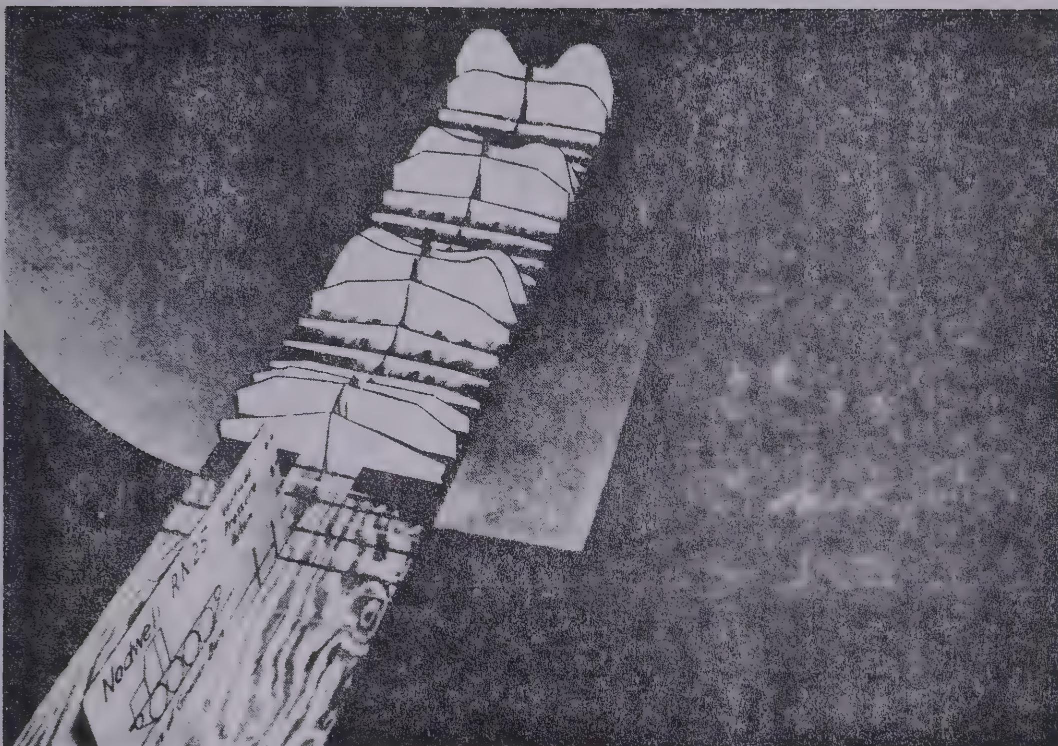


Fig. #11 - Stress Distribution

Fig. #12 - Weasel

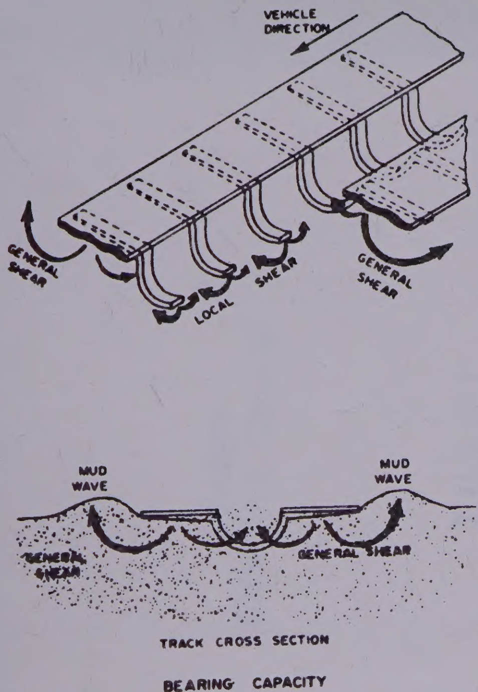


Fig. #13 - Shear Deformations

Fig. #14 - Wheel Loading

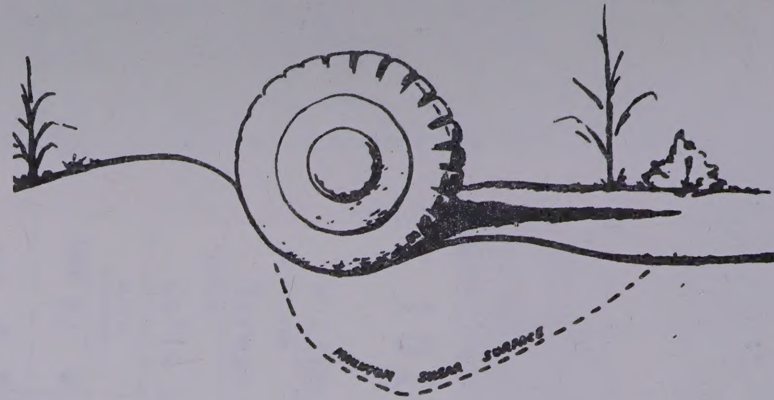
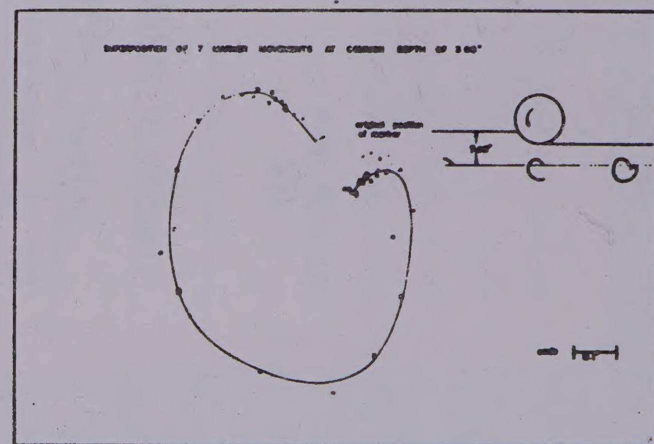


Fig. #15 - Soil Displacements



TYPICAL COMPOSITE CARDIOID